BELLCOMM, INC.

SUBJECT: Unified S-Band Circuit Margins
for the High-Altitude Phase of
Mission AS-501 - Case 320

DATE: June 15, 1967

FROM: J. E. Johnson
J. P. Maloy

ABSTRACT

Circuit margins for the Command and Communications System (CCS) and Unified S-Band System (USB) have been calculated for the high-altitude phase of mission AS-501. Only three ground stations are involved in this phase - the DSN and MSFN stations at Ascension and the MSFN station at Carnarvon. A fixed high-gain antenna will be used on the S-IVB/IU; however, the CSM will not have a high-gain antenna, and will be required to relay on a pair of the four elements of its omni antenna. CCS 72 kbps telemetry, updata, and ranging margins at Ascension are adequate as long as the S-IVB/IU attitude is optimized for communications (as it will be up to apogee). USB 51.2 kbps telemetry margins for the CSM, when computed for (1) a bit-error rate of 10^{-6}, (2) the operational trajectory, and (3) the nominal values of equipment parameters, are low at both Ascension and Carnarvon, and the margin becomes zero for a brief period following the first SPS burn over Ascension. Near apogee the CSM telemetry margins are below + 1 db. Computed USB margins for voice, updata and ranging are adequate. These margins are consistent with those reported by MSC/ISD.

MEMORANDUM FOR FILE

Introduction

An analysis of CSM Unified S-Band (USB) and S-IVB/IU
Command and Communications System (CCS) communications between the
Apollo space vehicle and facilities at Ascension and Carnarvon
was made for the high altitude phase of the AS-501 mission to
determine their capability for meeting mission requirements.
Significant mission events during this phase with respect to
each of these stations are listed in Table 1. The analysis was
performed using a full scale omni element antenna pattern for
the CSM, MSFC antenna patterns for the S-IVB/IU and a Bellcomm
computer program to calculate margins for USB and CCS links.
VHF performance will be limited for use at slant ranges less
than about 1000 nm, and the USB system will be the prime CSM
communications system past this range. The launch vehicle (LV)
will have both CCS and non-coherent S-Band links providing PCM
telemetry data during this phase.

Shortly after separation, the S-IVB/IU and CSM will not
be in the same antenna beam so that it will be necessary to
use both the Manned Space Flight Network (MSFN) and Deep Space
Network (DSN) S-band stations at Ascension. The present plans
have Ascension configured as two single stations and one will be
assigned to each vehicle. Carnarvon will time-share its facilities,
with prime emphasis on the CSM.

The trajectory used was designed for a mission date of
February 15, 1967, (References 2 and 3). The attitude of the CSM
will vary with launch date and time due to thermal constraints.
The effect of this variation upon circuit margins is not included
in this analysis. The actual margins will obviously depend on
the actual trajectory flown and will be considered in the mission
planning as the launch date becomes firm.

Procedures

Slant range vs. time values for the launch vehicle (LV)
were taken from reference 3 for the time period of interest.
After separation of the S-IVB and CSM, in accordance with reference 4,

an S-IVB/IU attitude was assumed for best communications between the vehicle and the Ascension Island DSN site with the vehicle roll axis perpendicular to the line-of-sight from the vehicle to Ascension Island ($\theta = 90°$) and "Position I" toward the site ($\phi = 180°$). No calculations were made after 5 hours and 49 minutes, at which time the LV is to be reoriented with the vehicle roll axis along the local horizontal and Position I toward the center of the Earth.

Figure 7 of reference 2 was used to determine the look angle from the MSFN to the CSM for points along the CSM trajectory. The look angle has two components, a pitch component (θ) and a roll component (ϕ). The pitch angle varies from 0° at the nose to 180° at the tail. The roll angle 0° reference is the - Z spacecraft axis (CSM hatch), with ϕ increasing counter-clockwise looking aft. CSM omni antenna elements are located at $\phi = 45°$ (D element), $\phi = 135°$ (A), $\phi = 225°$ (B), and $\phi = 315°$ (C). For mission AS-501, two of these elements, either A and C, or B and D, will be fed in parallel. The choice of element pairs will be made shortly before launch. There will be no in-flight switching. Margins are better for the trajectory assumed for this analysis if the A-C pair is selected. The results are based upon use of the A-C pair. The θ and ϕ components from reference 2 were used with the Block II D-omni element full-scale pattern to obtain antenna gain values. It was assumed that the A element pattern would be the same as the D, but shifted along the roll axis by 90°. The C antenna element is 180° from the A and its pattern was assumed the same as the A element except for the addition of 0.7 dB loss, since this antenna is covered by ablative material. Subsequently, these values plus slant range values from Ascension and Carnarvon from the referenced document were used as inputs to the computer program (Ref. 9).

Spacevehicle and MSFN Equipment Parameters

The spacevehicle and MSFN equipment parameters used for the margin calculations are listed in Tables 2 and 3. The CSM parameters are, for the most part, as-measured values on CSM 017 (Ref. 7). The LV parameters are taken from the MSFC Performance and Interface Specification for Saturn V Vehicles (Ref. 5). The MSFN parameters are taken from the CSM/MSFN Performance and Inter-face Specification (Ref. 6) and from a computer printout by MSC (Ref. 8). Nominal values were generally used. These parameters together with the slant range and spacevehicle antenna gains as determined above, comprise the required inputs to the calculation program.

Margins were calculated for the following cases:

(1)   CCS margins using the DSN Ascension station (SEN)
      from 3 hrs. 17 min. to 5 hrs. 40 min. The uplink
      mode consisted of PRN ranging and updata, the down-
      link mode PRN ranging and 72 kbps telemetry.

(2)   USB margins using the MSFN Ascension station (ACN)
      from 3 hrs. 24 min. to 7 hrs. 0 min. The uplink mode
      consisted of PRN ranging and updata, the downlink
      mode PRN ranging, 51.2 kbps telemetry, and a 400
      Hz tone to simulate voice.

(3)   USB margins using the MSFN Carnarvon station (CRO)
      from 5 hrs. 30 min. to 8 hrs. 15 min. The same mode
      was used as was used for ACN.

The results are shown in Figures 1-3.

Discussion of Results

CCS Margins - Ascension - Figure 1 shows the results of
the CCS margin calculations for the DSN station at Ascension (SEN).
This station is practically identical to the MSFN station, the
major difference being that the DSN station does not have a
cooled parametric receiver. This was taken into account by
assuming a receiver noise temperature (quiet sky) of 210°K for
the DSN station vs. 96°K for the MSFN station.

With the attitude constraint imposed on the S-IVB/IU
until apogee, CCS margins are comfortable. The look angle
coordinates of $\theta = 90°$, $\phi = 180°$ result in highly favorable
antenna gains. These values were chosen to optimize communi-
cations margins. The antenna patterns used in this study were
exclusively for SLA panels closed. During this phase of the
mission, the SLA panels will be open. Although no patterns with
panels open were available for this study, patterns for other
missions tend to indicate that slightly better gains might be
achieved by choosing a larger value of θ (moving further away
from the panels and toward the tail).

It is planned to switch from the omni on the downlink
to the low-gain directional configuration at T + 4 hrs. 30 min,
and to the high-gain directional configuration at T + 5 hrs.
25 min. This accounts for the discontinuities shown in the
downlink curves on Figure 1.

USB Margins - Ascension - Figure 2 shows the results
of the USB margin calculations for the MSFN station at Ascension
(ACN). These margins depend on CSM attitude. If the CSM

attitude departs significantly from the values taken from the trajectory used (Ref. 2, which assumed a mission date of February 15, 1967 and an 8:00 AM EST launch), the margins could differ significantly from those shown. The differences could be either positive or negative.

Margins appear adequate for updata, down-voice (simulated) and PRN ranging, but are obviously low for telemetry (51.2 kbps, 10^{-6} BER). The zero value obtained at T + 3.75 hours results from a CSM attitude reorientation following the first SPS burn. Actually, this computed margin value is fairly optimistic, because an attitude deviation of 2° at this time could reduce the margin to -12 db. Sensitivity to small changes in attitude was checked for each point; this was the only extremely sensitive point. Margins near apogee might be expected to vary only 1 or 2 db with small attitude changes.

USB Margins - Carnarvon - Figures 2 and 3 show USB margins at Carnarvon. Carnarvon margins were calculated assuming a 96°K parametric amplifier receiver. As was the case at Ascension, telemetry margins are low. The negative telemetry margins during the early part of the pass are associated with the near apogee location of the spacecraft. Ascension provides better margins at this time. It is planned for Carnarvon to be in contact with the S-IVB/IU from 5 hrs. 30 min. to 6 hrs. 15 min, and to reconfigure for CSM contact starting at 6 hrs. 21 min.
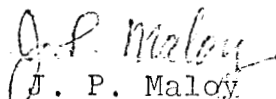
Conclusions

USB and CCS margins as predicted at Ascension and Carnarvon appear to be quite satisfactory through the high altitude phase for PRN ranging, updata, and simulated voice. The updata margins are very nearly independent of time, showing that the system is operating at a strong uplink signal level and the updata performance is limited by the subcarrier power and the range code in the receiver.

CCS telemetry margins appear adequate. USB telemetry margins near apogee are barely positive, and could be negative if attitudes and/or equipment parameter values are poorer than nominal, or if the actual mission launch time results in nominal CSM attitudes less favorable than those for the assumed launch time of 8:00 AM EST, Feb. 15, 1967. The elimination of updata and PRN during the marginal telemetry periods would result in a one to two db improvement in telemetry margins.

The results of this study are in general agreement
with those of the TRW study (Ref. 2). Different antenna
patterns and equipment parameters result in some differences
in margin levels, with TRW's results being somewhat higher.
Both studies used the same operational trajectory. The TRW
studies did not include the CCS.

J. E. Johnson

J. P. Maloy

2034-$\frac{JEJ}{JPM}$-jad

Attachments
  Tables 1-3
  Figures 1-3

TABLE 1

Significant Events in Mission AS 501 Following S-IVB Second Burn

(Reference Numbers 2, 11, 12, and 13)

Time hr: min: sec:	Event
3:26:55	RCS ullage for CSM/S-IVB separation
3:26:57	CSM/S-IVB separation
Within 5 min. of separation	S-IVB/IU reorientation with roll axis perpendicular to the line of sight from the vehicle to Ascension Island and Position I toward Ascension
3:27:05	CSM reorientation to SPS ignition attitude
3:27:45	Attitude hold for 50 secs
3:28:35	First SPS ignition
3:28:59	First SPS cutoff
3:29:00	Coast to apogee
4:30:00	S-IVB/IU switch from omni to low-gain antenna for CCS downlink transmission
5:25:00	S-IVB/IU switch from low-gain to high-gain antenna for CCS downlink transmission
5:30:00	S-IVB/IU handover from Ascension DSN station to Carnarvon for support of CCS tests
5:36:52	S-IVB/IU apogee
5:48:43	CSM apogee
5:49:00	S-IVB/IU roll axis reoriented along the local horizontal and Position I toward the Earth
6:15:00	Carnarvon drops CCS; reconfigures for USB
6:21:00	Handover from Ascension MSFN station to Carnarvon for CSM support

Table 1 (cont.)

Time	Event
7:04:00	Ascension LOS
8:01:09	Reorient to 2nd SPS ignition attitude
8:14:00	RCS ullage for 30 secs.
8:14:30	2nd SPS ignition
8:15:00	Carnarvon LOS
8:19:08	2nd SPS cutoff

BELLCOMM, INC.

TABLE 2

Parameters Used for IU CCS Margin Calculations

Parameter	Value	Source (Ref. No.)
Uplink frequency	2101.8 mHz	5
Ground transmitter power	10.0 kw	5
Ground transmit circuit losses	0.5 db	5
Ground transmit antenna gain	43.0 db	5
IU receive circuit losses	5.0 db	5
Updata modulation index	0.61 rad	8
Uplink PRN modulation index	0.3 rad	8
IU carrier detector noise bandwidth	400 Hz	5
IU updata detector noise bandwidth	20 kHz	5
IU transponder video noise bandwidth	1.8 mHz	
IU transponder IF noise bandwidth	4.0 mHz	5
Up-carrier S/N threshold	12.0 db	
Updata S/N threshold	10.0 db	5
Updata subcarrier center freq. offset from carrier	70.0 kHz	10
Low signal input noise temp. to IU transponder	1881.8°K	
Modifying constant for IU noise temp.	1.56×10^{14}	
Downlink frequency	2282.5 mHz	5
IU transmitter power	20.0 w	5
IU transmit circuit losses	3.0 db	5

Table 2 (Cont.)

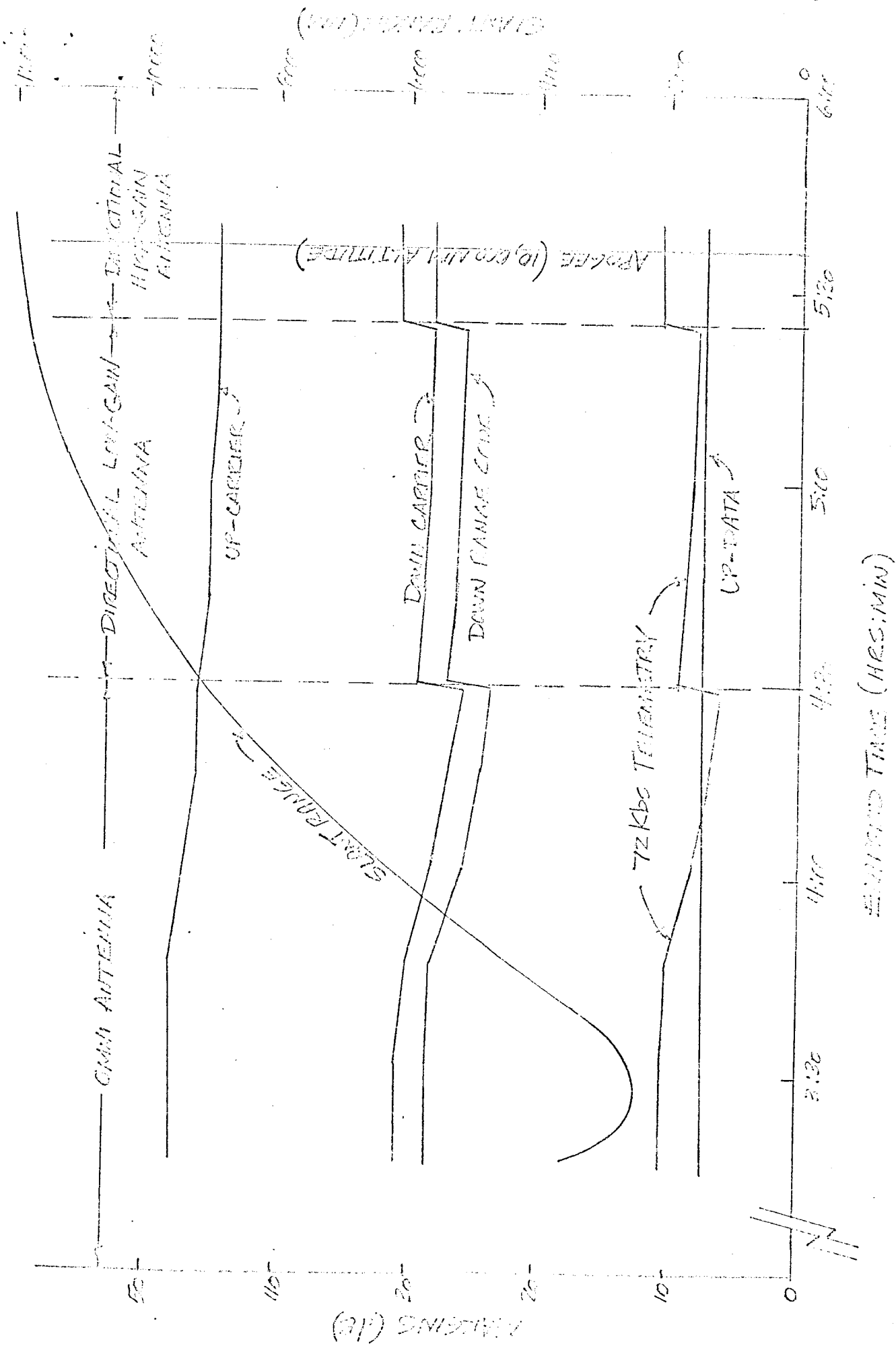|		
Ground receiver antenna gain	44.0 db	5
Ground receive circuit losses	0.5 db	5
Telemetry modulation index	1.22 rad	
Down-carrier detector noise bandwidth	700 Hz	5
Telemetry detector noise bandwidth	180 kHz	6
Down-range code detector noise bandwidth	1.0 Hz	5
Down-carrier S/N threshold	12 db	6
Telemetry S/N threshold (BER=10^{-6})	8.5 db	5
Down-range code S/N threshold	32 db	5
Ground receiver noise temp. (quiet sky)	210°K	
Modifying constant for receiver noise temperature	3×10^{15}	
Combined polarization and pointing losses	3.0 db	8
Transponder turn-around constant	1.5 db	8
($\frac{\sqrt{2}}{2}$ x transponder ranging gain constant)		

TABLE 3

Parameters Used for CSM USB Margin Calculations

Parameter	Value	Source (Ref. No.)
Uplink Frequency	2106.4 mHz	7
Ground transmitter power	10.0 kw	6
Ground transmit circuit losses	0.5 db	5
Ground transmit antenna gain	43.0 db	6
CSM receive circuit losses	11.7 db (A omni)	7
	11.2 db (C omni)	7
Updata modulation index	0.61 rad	8
Uplink PRN modulation index	0.3 rad	8
CSM carrier detector noise bandwidth	320 Hz	8
CSM updata detector noise bandwidth	21.0 kHz	8
CSM transponder video noise bandwidth	1.7 mHz	8
CSM transponder IF noise bandwidth	9.0 mHz	8
Up-carrier S/N threshold	12.0 db	8
Updata S/N threshold	10.0 db	8
Updata subcarrier center frequency offset from carrier	70.0 kHz	10
Low signal input noise temp. to CSM transponder	6500°K	
Modifying constant for CSM noise temp.	4.4×10^{14}	
Downlink frequency	2287.5 mHz	6
CSM transmitter power	11.5 w	7
CSM transmit circuit losses	8.0 db (A omni)	7
	6.0 db (C omni)	7

Table 3 (cont.)

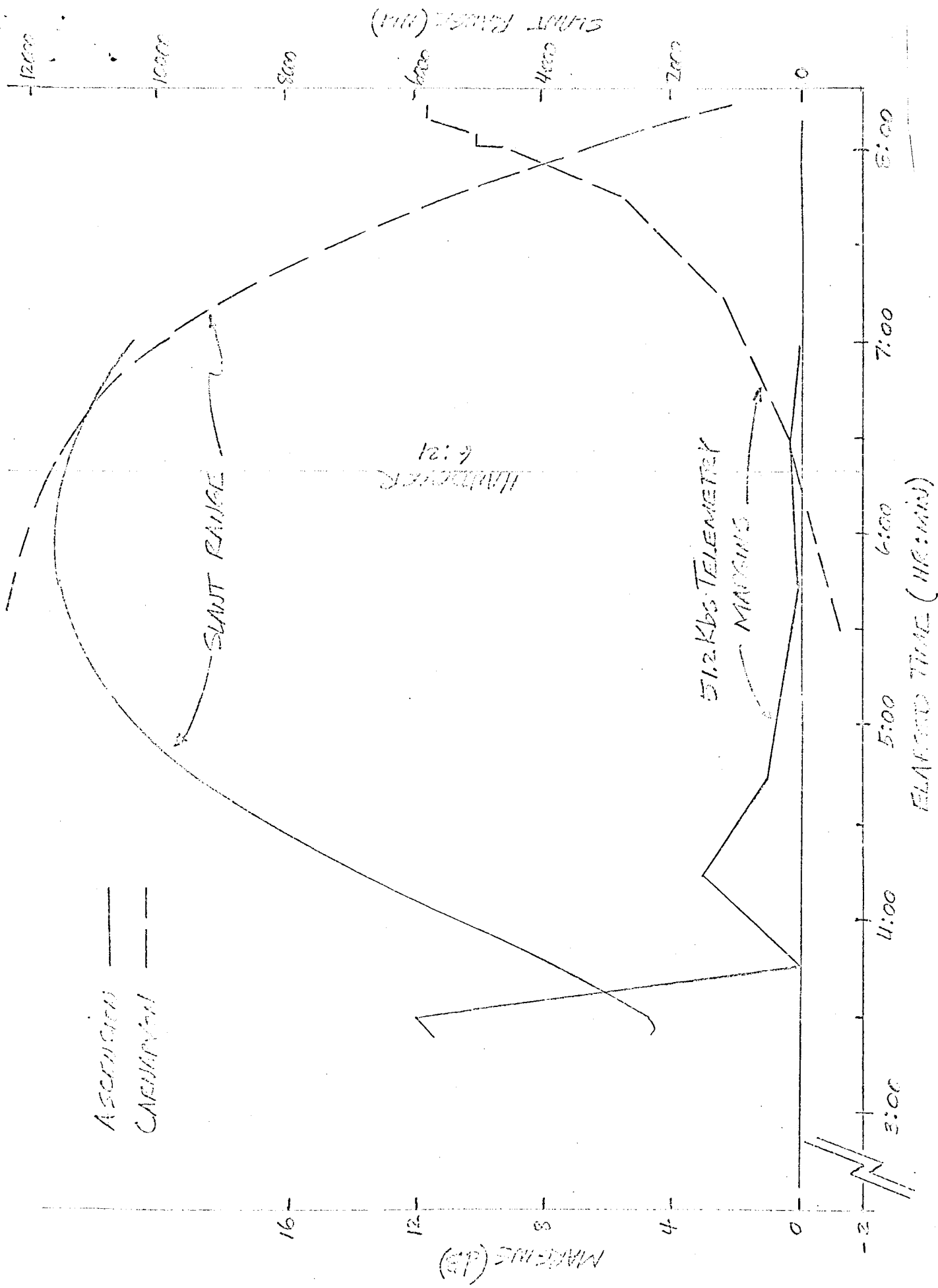|		
Ground receiver antenna gain	44.0 db	6
Ground receive circuit losses	0.5 db	6
Down-voice modulation index	0.87 rad	7
Telemetry modulation index	1.06 rad	7
Down-carrier detector noise bandwidth	700 Hz	8
Down-voice detector noise bandwidth	24.0 kHz	8
Telemetry detector noise bandwidth	180.0 kHz	8
Down-range code detector noise bandwidth	1.0 Hz	8
Down-carrier S/N threshold	12.0 db	8
Down-voice S/N threshold	8.0 db	8
Telemetry S/N threshold (BER=10^{-6})	8.5 db	8
Down range-code S/N threshold	32.0 db	8
Ground receiver noise temp. (quiet sky)	96°K	
Modifying constant for MSFN receiver noise temperature	3×10^{15}	
Combined polarization and pointing loss	3.0 db	8
Transponder turn-around constant ($\frac{\sqrt{2}}{2}$ x transponder ranging gain constant)	1.5	8

GRAIN ANTENNA

DIRECTIONAL LOW-GAIN ANTENNA

DIRECTIONAL HIGH-GAIN ANTENNA

UP-CARRIER

DOWN CARRIER

DOWN RANGE CODE

UP-DATA

72 Kbs TELEMETRY

SLANT RANGE

APOGEE (10,500 MLA ALTITUDES)

(SATELLITE ALTITUDES)

SLANT RANGE (KM)

MARGINS (db)

ELAPSED TIME (HRS:MIN)

2:30   4:00   4:30   5:00   5:30   6:00

SIVE/EU - CCS CIRCUIT MARGINS AT ASCENSION/(SEN) FOR AS 501
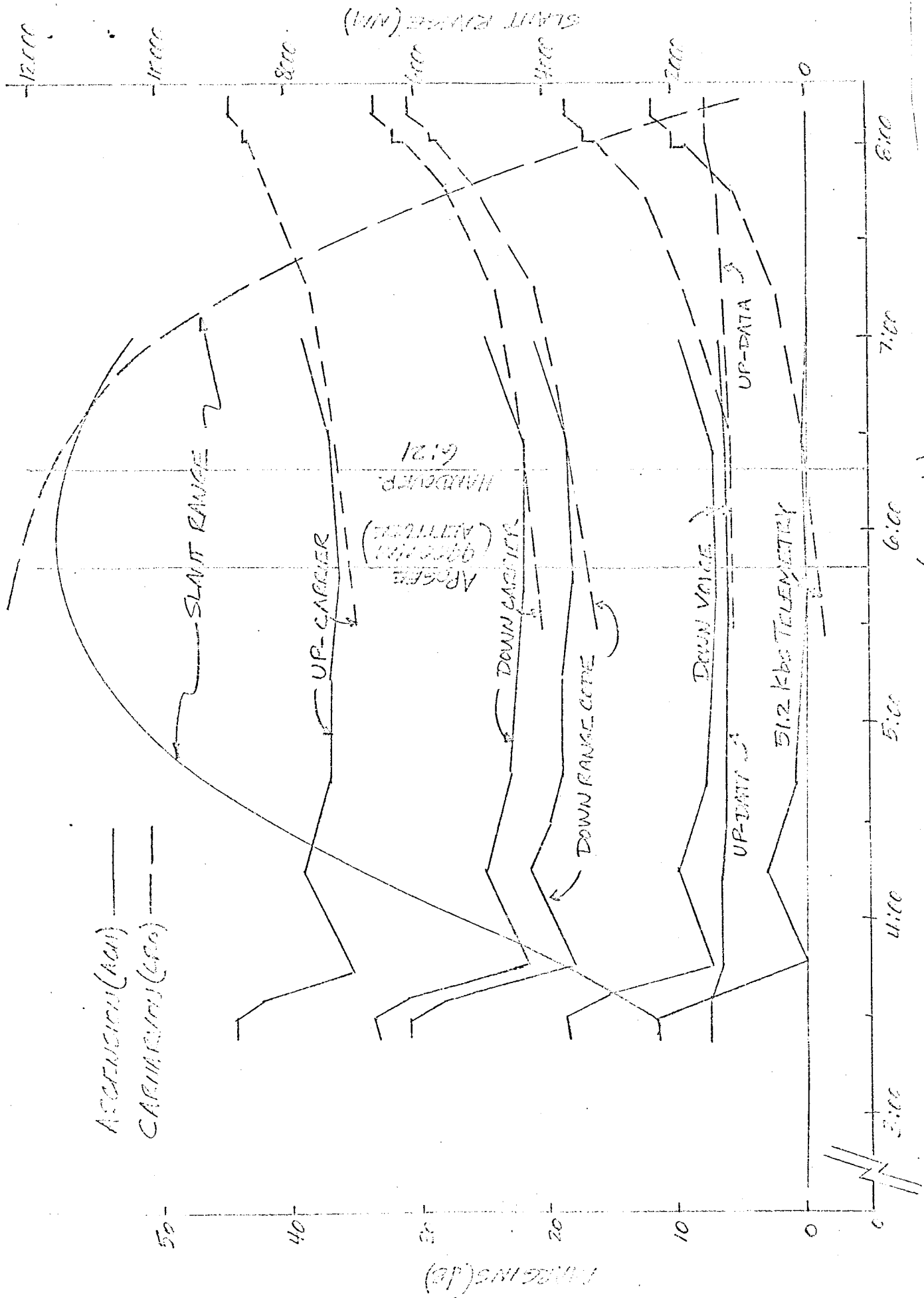
FIGURE 1

CSM-USB CIRCUIT MARGINS FOR ASCENT

FIGURE 3

CSM - USB CIRCUIT MARGINS FER AS 501 + 57.2 Kbs TELEMETRY

FIGURE 3

BELLCOMM, INC.

REFERENCES

1. "Range Safety Data Saturn V SA-501", Document Number D5-15497-1, The Boeing Co., 15 September 1966.

2. "Preliminary Apollo Communication Compatibility Analysis Mission AS-501 Revised" Apollo Communication Systems ASPO Task 9B Technical Report, Document Number 05952-H107-RO-01, 13 February 1967, TRW Systems.

3. "Tracking and Telemetry Analysis for Apollo/Saturn V AS-501 Operational Trajectory," Document Number D5-15454-11, Vol. II of II, September 1, 1966, The Boeing Co.

4. "Trajectory Document No. 66-FMP-21, AS-501, Joint Operational Constraints," MSFC and MSC, November 15, 1966.

5. "Saturn V Launch Vehicle Instrumentation/MSFN Performance and Interface Specification," Document Number 50M13106, MSFC, August 1, 1966. (Not approved by NASA Contract Specification).

6. "GFE Command and Service Module-Manned Space Flight Network Signal Performance and Interface Specification Block II," NAA SID 64-1613A, November 22, 1966. (Not approved by NASA Contract Specification).

7. "S/C 017 USB Subsystem Parameters," Attachment to letter to GSFC from MSC/ISD, February 27, 1967 (which in turn was an attachment to Ref. 2).

8. MSC parameter listing, untitled and undated (computer printout received by Bellcomm March 27, 1967).

9. "A Computer Program for Calculating the Communication Performance of Some Phase Modulated Apollo Unified S-Band System Modes," Bellcomm Memorandum for File by J. D. Hill, June 24, 1965. (Note: Program has subsequently been modified).

10. "GFE Command and Service Module - Manned Space Flight Network Signal Performance and Interface Specification Block I," NAA SID 64-1866, February 22, 1965.

11. "AS-501 Spacecraft Operational Trajectory," Volume 1 of 3, TRW Note No. 66-FMT-454, Document Number 05952-H067-RO-00, TRW Systems, November 15, 1966.

12. "Unified S-Band System Flight Verification Test Program Plan for Mission AS-501, Document Number EB-67-3131(U), MSC/ISD, May 12, 1967.

13. "Saturn V AS-501 Launch Vehicle Operational Flight Trajectory Final (U)," Vol. II of II, Document Number D5-15551(F)-1A, The Boeing Co., April 3, 1967 (confidential).